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COAL-MINE FIRES OF ELECTRICAL ORIGIN: THEIR CAUSE AND PREVENTION

BY

E. J. GLEIM

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF MINES

COAL-MINE FIRES OF ELECTRICAL ORIGIN: THEIR CAUSE AND PREVENTION[1]

By E. J. Gleim[2]

INTRODUCTION

A study of the records on file in the Bureau of Mines reveals that many fires in coal mines have been started by electrical equipment or circuits. Where the fires were of undetermined origin, electricity often was strongly suspected as the probable cause. While it is unfortunate that positive evidence as to the cause is so often lost in the general destruction resulting from fires, there are many lessons to be learned from fires in which the origin was definitely established as electrical.

For modern high-speed methods of producing coal, electrically operated machinery has become virtually indispensable underground. With increases in the amount of equipment it has not always been necessary to increase the number of circuits in the mine where direct current is mainly used, but it has been necessary to increase the carrying capacity of these circuits. For example, loads such as heavy-haulage units drawing 1,000 amperes or more have brought about the introduction of 6/0 and "No. 9 section" trolley wires. This has not made the task of fire prevention any easier, for it has meant that circuit breakers must be set so high that partial short circuits fail to open them, therefore an arc of considerable proportions can be maintained without causing the breaker to open. Thus, if a fall of roof brought a trolley wire down against a loaded car of coal, an arc might be struck that would ignite the coal without opening the circuit breaker.

A statement by W. H. Gates[3] confirms this. He says, "Practically all of our mine fires have been from falls of roof coal bringing down a trolley wire which did not short sufficiently to trip a circuit breaker and so fired the coal."

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 6981."

2/ Electrical engineer, Bureau of Mines, Pittsburgh Experiment Station, Pittsburgh, Pa.

3/ Gates, W. H., Discussion of G. S. McCaa's Paper: Coal Mining, vol. 13, 1936, pp. 7-9.

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In a study of 55 fires occurring in metal mines of one district over a period of 12 years (1917-28, inclusive), F. C. Gregory[4] learned that 22, or 40 percent, were probably of electrical origin. Of those 22, 10 were attributable to trolley or lighting circuits. Bulletin 229,[5] which describes how 59 coal-mine fires occurring during a period of 16 years were fought and the lessons learned from them, includes 4 fires whose origin was traced to electrical equipment or wiring.

This paper purposes to discuss electrical fire hazards observed in the inspection of coal mines, to describe briefly some fires of electrical origin, and to point out precautions that should be observed to prevent similar fires.

Some Fire Hazards and Their Elimination

There are many practices in connection with underground machines and circuits that would not be tolerated in large, well-organized factories where every precaution for the prevention of fires is demanded by insurance agencies. It is true that other industries do not encounter the same difficulties as coal mining, but this does not excuse unsafe practices. The very difficulties such as falling roof and advancing workings, which hamper the making of adequate support and the extension of circuits, call for unceasing effort and ingenuity to prevent the development of fire hazards.

The following conditions, which should be regarded as fire hazards even though no mine fire has been positively traced to every one of them, are taken from the observations of Bureau engineers:

1. In many locomotive headlights the front lens was missing and the bulb was supported by rags, waste, or paper to keep it from rattling and breaking against the headlight body. The author has seen rags burst into flame in a headlight on a locomotive traveling against the air. The motorman in this instance stopped to remove the rags and stamp out the blaze, but burning parts might have dropped out unnoticed among loose coal along the track and thus have started a fire. The remedy for such a condition is to keep headlights in good repair so that the bulbs will not require makeshift supports.

2. Paper and cardboard have been used as shields and reflectors around lamp globes. This material is combustible and is not difficult to char if left in contact with globes, particularly large ones such as might be used in weigh rooms, dispatchers' offices, and other underground rooms. Shields and reflectors should be made of metal or other incombustible material.

4/ Gregory, F. C., Fires and Fire Prevention in Lake Superior Mines: Inf. Circ. 6073, Bureau of Mines, 1928, pp. 1-17.

5/ Rice, G. S., Paul, J. W., and von Bernewitz, M. W., Fifty-nine Coal-mine Fires: Bull. 229, Bureau of Mines, 1927, 156 pp.

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3. To avoid difficulties arising from dampness it has been common practice to mount mine telephones in wooden boxes with a lamp bulb inside (usually under the telephone) to supply heat for keeping the telephone dry. Often no attempt has been made to fasten the lamp socket to the box, and the bulb is allowed to rest against the wood. It would be preferable to fasten the socket securely to the box so that the bulb cannot touch any wood.

4. One flagrant neglect in wiring, especially in connecting lighting circuits to trolley circuits for lamps at track switches and pump rooms, is the fastening of the conductors to wooden posts, cross bars, and frames by means of nails clinched over the conductors. If the nails do not press through the insulation immediately, they may easily do so as the insulation deteriorates, and ultimately there may be a ground or short circuit. In addition, poorly made splices may arc and heat up, finally setting fire to the insulation. For these reasons, all wiring, including return wires of direct-current systems, should be mounted on insulators so that the conductors will not touch any wood, coal, or other inflammable materials. Where they must be taken through wood, conductors, even though insulated, should be provided with porcelain or other suitable incombustible bushings or tubes inserted in the wood. The foregoing precautions apply to wiring for pump and other installations as well as to that for lighting circuits.

5. Direct-current trolley and feeder circuits often touch wood crossbars, doorframes, and coal. Sometimes they are in contact with canvas and brattice cloth used in the construction of doors. Although wood, coal, brattice cloth, and canvas in dry condition may be classed as insulators for the voltage of ordinary trolley distribution circuits, changing conditions, such as saturation with acid mine water may cause them to become conductors of electricity. The leakage current may then create a fire hazard. The account of a mine fire as related by a safety engineer for a certain group of collieries shows that it is possible to start a fire under such conditions.

A piece of brattice cloth was used in sealing around a ventilating door. This cloth either was placed or came in contact with the trolley wire passing through the doorway. Movement of the air set the cloth to swinging against the head of a nail in the wooden doorframe, and current from the trolley wire traveling through the cloth jumped to the head of the nail and eventually heated it sufficiently to set fire to the timber. The suspected conditions were reproduced in order to prove that the fire was caused in this manner.

When trolley wire is permitted to remain in contact with the underside of wood crossbars, an unsafe condition may be created, especially at doorways where canvas or brattice cloth is used to close the space left around the wire. The trolley wheel of a passing locomotive may strike the wood, thus pressing the wheel away from the wire. The resulting flash, especially if the locomotive is heavily loaded, may ignite dry, loose ends of cloth or wood hanging around the wire.

Besides the foregoing hazards, the wire and feeder might carry current beyond their safe carrying capacity so that dry wood, canvas, and burlap

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would be charred by the heated conductor. The Bureau of Mines has conducted experiments to determine the amount of current required to char such materials when bare wires of different sizes are in contact with them. The results of these experiments are given in another part of this paper.

To minimize fire hazards resulting from wires touching wood, coal, and other combustible materials, every effort should be made to see that the capacity of the conductors is adequate and that the conductors are supported properly on insulators so that they do not rest against such materials. Subsidence of overlying strata may result in wires being brought against coal and timber; therefore, frequent inspections should be made to see that circuits originally spaced away from combustible substances have not been brought against them. Burying the cable or encasing it in a strong, incombustible conduit may prove to be the best way of eliminating this hazard.

6. The opening and closing of knife-blade switches and of air-break circuit breakers under load may introduce fire hazards either due to particles of melted copper falling among combustible material or to arcs and flashes directed against such material. One coal-mine fire was suspected of having originated from a spark thrown into timbers by an automatic circuit breaker. Because of this hazard, the places selected for mounting switches and circuit breakers should be chosen carefully with reference to surrounding inflammable substances, or this equipment should be enclosed in metal or other fireproof housings that will prevent the escape of sparks and flashes.

7. Wires and cables that may be of ample carrying capacity for rated loads can overheat and become a fire hazard when the rated loads are exceeded if suitable overload protection is not employed to open the circuits before dangerous temperatures are reached. Sometimes pump circuits have no protection whatever or heavy copper wire has been substituted for fuses, which amounts to virtually the same thing. Trolley taps for attaching trailing cables of mining machines and other portable equipment to feeder circuits often have pieces of trolley wire instead of fuses in them. Without the protection afforded by fuses, overload relays, or their equivalent, a ground or short circuit in a machine may easily set fire to the insulation of the machine or the wiring to it. To avoid this hazard, it is first necessary to provide protection correctly proportioned for the wiring and machines to be protected and then to remove short circuits and other conditions that demand current above the rating of the protective devices. In other words, if a 5-horsepower pump motor is rated at 20 amperes full load, the motor should not be loaded continuously beyond its 20 amperes of rated capacity, and the electrical protection should not be 100-ampere fuses but those that would prevent such overloading by automatically opening the circuit.

8. Rail bonds may be another fire hazard in a mine. If rusting or vibration loosens the bonds or they are cut in two by derailments, the return current in jumping the gap easily results in arcing capable of igniting coal that has accumulated along the track. Fires have been known to start in this manner. There are two steps to be taken in the removal of this hazard: (1) Tracks should be kept clean so that coal does not pile up at rail joints;

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(2) bonds should be inspected regularly and checked with a bond tester to locate loose and defective bonds which should be replaced before arcing takes place.

9. Electric heaters are convenient for heating underground rooms, such as dispatchers' offices, repair shops, and weigh rooms. If these heaters are carelessly used or not properly placed with respect to inflammable materials, they become a fire hazard. Sometimes heaters are constructed of scrap materials around the mine and not enough care is exercised to provide a suitable frame or support for the heating elements. If the fire hazard is to be avoided, it is essential that heaters be shielded so that combustible substances cannot fall or be placed against the heating elements. Moreover, heaters either should have broad substantial bases for stability or should be fastened to the wall or other satisfactory support to prevent their falling against anything that might catch fire.

10. Resistors for motor-starting duty and other service often develop considerable heat. This may be the result of overloading or of poor connections. In any event, resistors for pumps, hoists, and other stationary equipment should be placed at a safe distance from the coal and timber to reduce fire hazards. Moreover, suitable guards or shields should be provided to keep coal and other substances that will ignite from falling into or being placed on the resistors.

11. Mining machines are often thickly coated with coal and grease. Likewise, pumps often have accumulations of oily waste and grease around them. As cleanliness is a very important factor in fire prevention it is wise to insist upon thorough cleaning of all locomotives, mining machines, pumps, and other underground electrical equipment at regular and frequent intervals so that if wiring becomes defective there will be a minimum of inflammable materials to catch fire.

12. Occasionally reels of trailing cable burn. Fires in trailing cable usually are caused by defective splices. Unless splices are made carefully they will have high resistance and will heat. Then, if the splices loosen, arcing will occur and set fire to the insulation. Sometimes a cable will short-circuit and take fire at a splice because the joint has not been properly insulated. To reduce the hazard of fire in cable reels, splices must be made electrically and mechanically strong. It is equally important that splices be made to exclude the entrance of moisture so that there will be no short circuits from this source. This is best accomplished by vulcanizing the splices.

Some Fires of Actual or Suspected Electrical Origin

From 1931-36, inclusive, Bureau field engineers reported on at least 31 fires in coal mines, of which 14, or nearly half, were either definitely known to be or else strongly suspected of being electrical in origin.

In the following paragraphs the fires in which electricity was given as the actual or probable cause are described briefly. Unless otherwise stated these mines produced bituminous coal.

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1. A fire in a certain mine started between shifts. It was thought that the night crew in coming off its shift left some clothes to dry in an improvised underground change house. The clothing probably came in contact with an electric heater or circuit and caught fire. In order to get water to the fire, a compressed-air line was converted into a water line; this required 1,000 feet of 2-1/2-inch fire hose. This was the third fire in this mine in 4 years.

2. A motor crew operating a cable-reel locomotive was about to couple onto a load when an arc was noticed at the bearing through which the cables enter the reel. This arc set fire to the cables, to the wooden parts of the reel, and to the grease and oil around the bearing. Attempts to extinguish the fire with water dipped up with a dinner bucket appeared to spread rather than check the fire, and it became necessary for the crew to retreat. Later, the burning locomotive was drawn by another locomotive to a crosscut where there was a pool of water. This water was used in fighting the fire, which was eventually extinguished.

3. This fire was attributed to the grounding of a live trolley wire against a door as the result of a fall, someone having forgotten to open the trolley switch in leaving the panel in which the fire was found. Hand extinguishers and water buckets proved ineffective in controlling the fire. The nearest water line was some 2,000 feet away. To get water on the fire from this line, 1,500 feet of pipe and 500 feet of hose were connected up in the record time of 2-1/4 hours after the material was ordered from the surface.

4. Another fire in which a cable-reel locomotive was involved started when roof coal fell on top of the locomotive. Soda-acid extinguishers brought from the outside were first directed on the fire. Later, it was possible to bring in 2 cars of water with which the fire was finally extinguished. This was the fourth fire in the mine in a year. Two of these necessitated sealing the mine.

5. The cause of another fire was assumed as a fall of roof in an underground transformer station, which caused a short circuit in the external wiring, or a short circuit in a transformer, which burned a hole in the casing and allowed flaming oil to discharge and ignite surrounding coal and other combustible material. Direct methods of fighting this fire proved futile, and it became necessary to seal that section of the mine. It has since been decided that the suspected transformers will not be removed from where they are undoubtedly buried, therefore it is unlikely that any evidence will ever be gained to prove or disprove the correctness of the assumption that the fire originated with the transformers.

6. A fire was discovered in a slope of an anthracite mine by an assistant foreman. The crew descending the slope to fight the fire found that an electric cable had ignited timbers at a pump station. The timbers fell into the sump and thus extinguished the fire.

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7. A short circuit in a mining-machine cable was apparently the cause of a fire. The cable passed through a wooden conduit under the mine track. The conduit had evidently rotted and the passage of a locomotive crushed it so that the cable was pinched, then short-circuited, and so caught fire. The flames spread from the wooden conduit to the coal but had not gained great headway when discovered. Therefore it did not prove difficult to extinguish this fire.

8. The next fire recorded was one that could not be controlled by direct methods, therefore the shaft and slope openings to the mine had to be sealed. The exact cause of the fire could not be determined; however, it was assumed that a live trolley wire had been brought down against some steel cars by a fall resulting in an arc that set fire to the coal.

9. Another fire in an anthracite mine occurred in the wood-lined shaft used for hoisting coal. The fire was of undetermined origin, but the management felt that a power cable short-circuited in a separate compartment of the shaft, setting fire to the timbers. The flames were extinguished with water from four hose lines directed on the fire by fire companies called from two nearby towns. The damage was so extensive that it was estimated that it would take 4 to 6 months to retimber the shaft and get it in operating condition once more.

10. Smoke issuing from the ventilating fan gave the first warning of fire in a certain drift mine. No firefighting equipment was available, but some tubs of water were taken inside to combat the flames. When these proved unsuccessful, a high-pressure rock-dust distributor was obtained from a neighboring mine and an attempt was made to extinguish the fire with rock dust. This also failed, and it became necessary to seal the mine. It was possible to examine the mine enough before the fire got completely beyond control to obtain evidence that loose brattice cloth used at a door had been ignited by a spark from a nip sliding along the trolley wire when the machine crew was taking a mining machine in for their night's work.

11. The cause of this fire was given as "probably a faulty rail bond or a jumper cable." Nearly 3 days were spent in trying to extinguish it by direct methods, and when this failed six seals were erected as close to the fire area as possible. When two of the seals were broken open several weeks later the fire rekindled. Then it was decided to build two concrete dams in the mine and flood the burning area.

12. Investigation of another mine fire pointed to the "blowing" of a cable to a coal-cutting machine as the probable cause; the arc set fire to loose coal. Eight hours or more were allowed to pass after the discovery of the fire before any effort was made to extinguish it. Finally, however, some 50-gallon drums were filled with water which was played on the burning material by means of a hose connected to an electrically driven centrifugal pump. The water had to be hauled nearly a mile in the mine, and 10 drums were transported at a time. The fire was brought under control in this manner. To insure that it was completely extinguished, water was hauled and pumped in to flood the area. A dam was erected to confine the water.

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13. While the headframe over an abandoned shaft was being dismantled, a heavy timber fell and struck an iron conduit that encased a 440-volt cable supplying current to a pump motor at the shaft bottom. The collar on which the conduit rested was of concrete, but the concrete extended only about 3 feet down. Below this the shaft was lined with wood. It was thought that when the timber struck the conduit it caused the cable to short-circuit and resulted in heating the conduit until the wood below the concrete ignited. From 500 to 600 feet of hose was laid in getting water to the fire, which was eventually extinguished before it could reach the shaft bottom. No fire-fighting equipment was available at the shaft.

14. A fire at first attributed to a set of small transformers gained considerable headway before its discovery. Portable extinguishers proved ineffective, and it became necessary to seal off that section of the mine. After a lapse of more than 2 months the seals were broken and the suspected transformers brought to the surface. Examination and test of these transformers revealed no evidence that they were directly responsible for starting the fire. However, in the removal of burned and fallen material from that part of the mine, three wires forming part of a transformer secondary feeder circuit were found to be fused off in two places. Moreover, a mass of fused copper which one of the men said included trolley wire as well as wires of the feeder circuit, was found in the same area. A fall may have brought the trolley and secondary circuit wires down together, resulting in arcing of sufficient intensity to ignite the coal.

Lessons From the Fires

The foregoing accounts of fires emphasize: (1) The general lack of organization, facilities, and equipment for fighting fires in coal mines; (2) the great expenditure of time and labor in getting water and other materials to the scene of the fire; (3) the huge losses in production, wages, and coal that usually follow when the mine has to be sealed, and (4) the expense of clearing the mine of falls and of repairing and replacing the damaged track, equipment, and timbering.

Stated briefly, some of the lessons that can be learned from the fires discussed are as follows:

1. Organize and drill for fighting fires.

2. Keep enough fire-fighting materials and equipment near at hand and in working condition. Materials should include rock dust, brattice cloth, hose, and pipe.

3. Keep unprotected and improperly designed power circuits out of the mine, particularly out of shafts and main entrances.

4. Use wires with carrying capacity large enough for the load to be carried.

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5. Disconnect all trolley, feeder, and other mine circuits not actually in use.

6. Keep all electrical circuits, including trolley wires, from touching wood, coal, canvas, and other combustible materials.

7. Keep rails of trolley return circuits well bonded.

8. Make splices in machine cables strong, well-insulated, and watertight.

9. Keep locomotives and machines free from accumulations of grease, coal, and oily rags.

10. Keep clothing and other combustibles away from heaters, rheostats, and electrical equipment that might become overheated.

11. Protect transformers and other stationary electrical equipment against falls.

12. Protect electrical circuits against falls and other mechanical damage as far as practical. This applies especially to trolley wires which ordinarily must be placed in a more exposed position than other circuits.

BUREAU OF MINES TESTS TO DETERMINE POSSIBILITY OF IGNITING COAL AND OTHER MATERIALS BY ELECTRICAL MEANS

With carbon electrodes an electric arc can be established in which temperatures of 6,000°F. or more are attained. Thus it may be judged that under certain conditions any material can be made to burn. However, the question arises as to how much danger there is of setting fire to coal, wood, and other combustible materials when low-voltage, live, bare wires rest against them.

The Bureau of Mines has made numerous tests in an effort to obtain the answer to this question. The results of the tests with coal were published in 1936 in Technical Paper 568, Hazard of Igniting Coal by Electric Circuits in Mines, by H. B. Freeman. In these tests it was found that the results varied greatly under different test conditions and with different samples of coal. In one set-up a certain sample of anthracite was ignited in 1 minute and 10 seconds by applying a potential of as little as 110 volts direct current between two electrodes placed 1 inch apart on the sample. On the other hand, bituminous coal could not be ignited under similar conditions or even with higher voltages. The explanation for this is that, in general, bituminous coal presents such a high resistance to the passage of electrical current that under ordinary circumstances it may be regarded as an insulator. The observed ignition of roof coal by current leaking over a defective insulator of a trolley hanger in a certain anthracite mine confirms the experimental results and indicates that much greater care needs to be exercised in keeping circuits clear of coal in an anthracite mine than in a bituminous-coal mine. However, it is not to be assumed from this that it is safe to allow live wires

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to remain in contact with bituminous coal indefinitely. If the wire is too small for the normal load to be carried or if a short circuit occurs, the temperature of the wire may easily reach a point where coal in contact with it would be ignited. Moreover, mineral charcoal or coking resulting from arcs may furnish low-resistance paths through which enough current would flow to raise the coal to the ignition temperature.

The Bureau's tests with other materials were not carried to the point of determining the conditions under which these materials would burst into flame but rather to establish safe carrying capacities for bare wires, should they come in contact with certain materials. The current necessary to heat wires to the point of producing slight discoloration of the specimen materials was chosen as the basis for determining safe values.

Ten samples of soft-drawn, solid, bare-copper conductor were selected and cleaned for the tests. These were of the following standard B. & S. gage wire sizes: Nos. 10, 3, 6, 4, 2, 1, 0, 00, 000, and 0000. The combustible materials comprised strips 2 inches wide of the following: Oak, white pine, maple, spruce, burlap, and canvas ("noninflammable brattice cloth"). The last two materials were stretched across a wooden frame for rigidity.

The wires were mounted one at a time in a horizontal position, and the smaller sizes were heated by current from a laboratory storage battery. The current required to heat the larger-size wires sufficiently was beyond the capacity of the storage battery, accordingly a special transformer was used for the purpose. In each test of a given size of wire the six samples of combustible materials were placed horizontally across the wire so that they would rest on it at right angles to the long dimension of the strips; that is, the length of contact between each sample strip and the wire was 2 inches. The samples were parallel and spaced a uniform distance apart. The current necessary to produce slight discoloration and that necessary to produce positive charring were determined for each of the wood samples. The duration of each test was 1-1/2 hours, as no additional charring resulted from prolonging the test beyond that time. The tests were made at room temperatures (17° to 25.5°C.) in still air.

Figure 1 shows the results of the tests for three sizes of wire. Complete data for all of the wires used are given in table 1.

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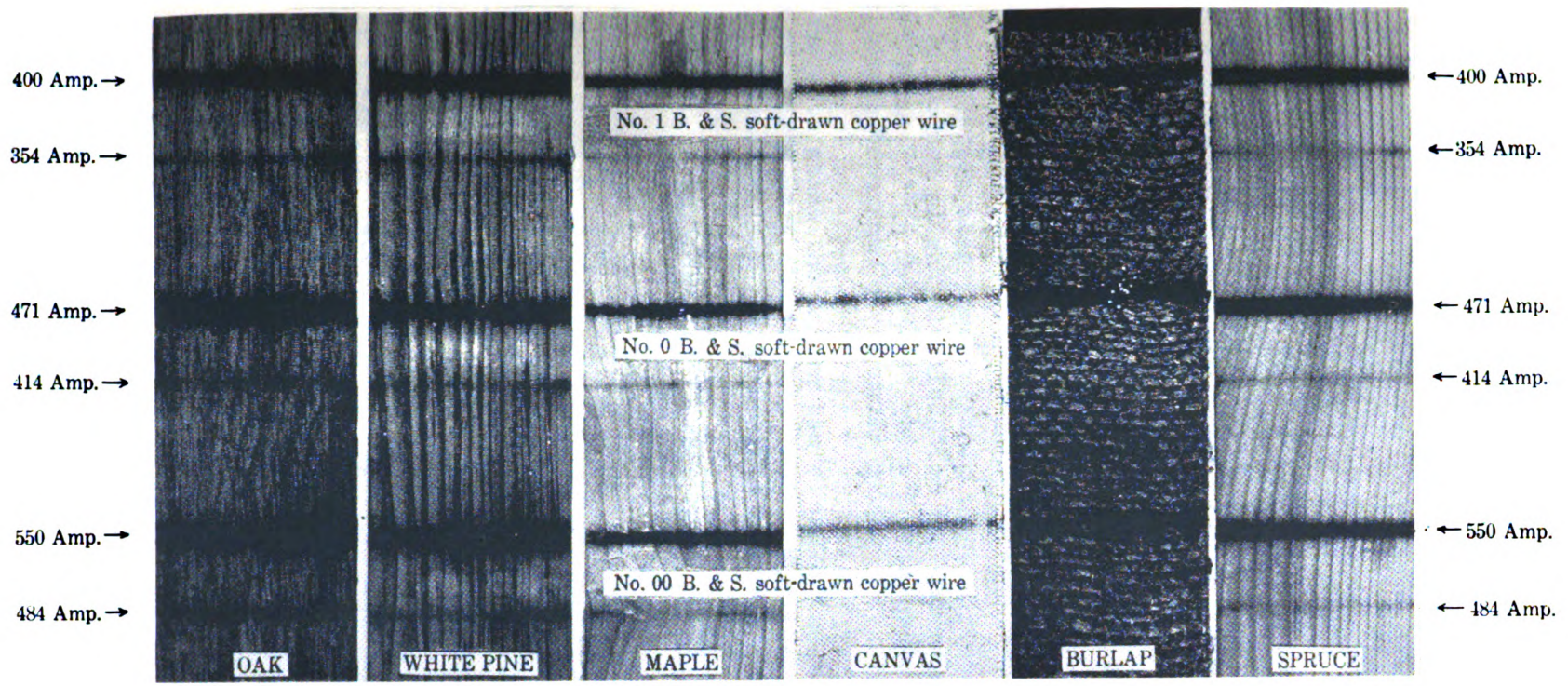

Figure 1.—Charring of combustible materials by heated electric wires.

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TABLE 1. - Currents necessary to produce charring and discoloration of combustible materials with different sizes of wires

Size of wire, B. & S. gage	Current values, amperes	
	For positive charring	For slight discoloration
10	100	90
8	130	115
6	178	161
4	255	230
2	345	310
1	400	354
0	471	414
00	550	484
000	660	583
0000	781	682

For wires larger than those used in the experimental work the current necessary to produce slight discoloration was determined from a curve whose equation is $Y^{1.4} = 0.07X$, in which Y represents hundreds of amperes and X represents thousands of circular mils.

The currents which the Bureau can recommend as the maximum that can be carried with safety were obtained by taking 90 percent of the values that gave slight discoloration. These maximum values are given in table 2.

TABLE 2. - Maximum current-carrying capacity of bare copper conductors

Size of conductor (B. & S. gage)	Amperes	Size of conductor (circular mils)	Amperes	Size of conductor (circular mils)	Amperes
10	80	250,000	690	750,000	1,520
8	105	300,000	790	800,000	1,590
6	145	350,000	880	850,000	1,660
4	210	400,000	965	900,000	1,730
2	280	450,000	1,050	950,000	1,800
1	320	500,000	1,140	1,000,000	1,870
0	375	550,000	1,215		
00	435	600,000	1,285		
000	525	650,000	1,370		
0000	615	700,000	1,450		

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STEPS IN FIRE PREVENTION

Fireproof Rooms and Vaults

Special precautions should be taken in the housing of electrical installations underground to prevent the spread of fire which may originate in the equipment. This is particularly true of substation and transformer installations having inflammable oil for the liquid dielectric in the circuit breakers and transformers. On account of the fire hazard involved with large quantities of such oil underground, the Bureau of Mines has never favored the unrestricted use of oil-filled transformers in coal mines.

Gunite[6/] reinforced with poultry netting or metal lath has been found satisfactory for fireproofing rooms. Walls also may be constructed of concrete or concrete blocks and the roof of concrete slab. Small concrete slabs cast between rails have been used in constructing "knock-down" transformer houses. The method followed is to place a number of rails web downward and parallel about 2 feet apart on a smooth surface. (This can be done outside of the mine where materials and facilities for mixing the concrete are most convenient.) The number and length of rails needed will depend upon the plan of the house to be erected. Concrete is then cast between the rails to their tops using heavy-paper partitions at right angles to the rails so as to divide the concrete into blocks or slabs about 2 feet square. When the concrete has hardened enough to permit handling, the slabs are removed and the rails taken underground where they are placed parallel as before across two others set next to the roof over the transformer station. The concrete slabs are then slid into place as originally cast, thus forming a fireproof roof. With channels and I-beams, other concrete slabs can be placed to form the sides of the station.

When the equipment contains large quantities of oil, as do transformers, the fireproof room should be made with doorsills high enough to prevent the escape of oil should the containers burst or spring a leak. A layer of sand and gravel several inches deep on the floor of transformer rooms should be used to soak up leaking oil.

Because of the heat generated in the operation of electrical equipment it is necessary to provide ventilation for substation and transformer rooms to prevent damage to the equipment from overheating. This means that fire doors are necessary to close off ventilating openings if the rooms are to be isolated when fire starts in them. In some transformer vaults steel doors are hung by horizontal hinges over the ventilating openings. The doors are held open by cords run through pulleys in the roof and then passed over the transformers so that flames from the transformers will burn the cord and allow the doors to drop. Sometimes fusible links are tied in with the cord to insure release of the doors. If the doorframe is inclined at a

6/ Pickard, B. O., Gunite in Metal Mines: Rept. of Investigations, 2397, Bureau of Mines, 1922, 30 pp.

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slight angle rather than vertically the door is more certain to seat tightly after it has been released. The closing of the doors can be made to trip the circuit-breaker in the primary lines to the transformers, thus reducing the danger of impressing a high voltage on the secondary or low-tension circuit when the transformer is damaged by fire.

Larger ventilating openings may be needed for substation rooms than for the usual transformer vault. The fire doors for the larger openings can be made of steel plates in two sections reinforced with angles. The two sections can be mounted on vertical hinges to form double doors held open as before by a cord or rope passing over oil switches and generating equipment. Counterweights can be arranged so that the doors will close when they are released by the burning of the cord or the melting of fusible links. Counterweights should be suspended by incombustible rope or chain and should be guarded so that they will always be free to travel the full distance required in closing the doors.

Portable Transformer Boxes

Self-contained portable transformer boxes have been used to some extent instead of fireproof rooms of brick, tile, or concrete. For this purpose boxes made of steel plate are mounted upon a mine-car truck to facilitate movement about the mine. The transformers are permanently fastened in place and connected up. The primary and secondary switches also are secured to the boxes. This arrangement permits the transformers and switches to be moved without disturbing the wiring between them, and as the box itself is the fireproof enclosure it is not necessary to tear down and build up fireproof walls each time the unit is moved. A further advantage is that the unit can be built, wired, and inspected on the surface where light and other conditions are conducive to better workmanship than is ordinarily possible when all the work must be done underground. Moreover, the portable unit minimizes the time and labor required to move the transformers from one position to another in the mine.

In one design the seams of the box are welded to prevent leakage of oil and the cover is left closed, as the walls of the box are thought to furnish enough radiation to prevent overheating. In another design, the sides of the box are bolted in place, but a layer of sand in the bottom is used to adsorb oil that may leak from the transformers. In this design the hinged cover is held partly open to allow the interior to be ventilated. If a fire starts in the box the cover is arranged to drop when a rope stretched inside the box burns in two and releases the cover supports. Whether or not such boxes are capable of confining flames within them if a transformer explodes is open to question. In the boxes described the covers probably would be blown off by an internal explosion.

Noninflammable Transformer "Oils"

Two large manufacturers of electrical equipment offer transformers filled with liquid dielectrics which are noninflammable. These dielectrics are described as "chlorinated hydrocarbons." Although these comparatively

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new dielectrics are reported virtually to eliminate the fire hazard that is present with the usual transformer oils, relatively large quantities of hydrochloric acid and carbon monoxide gases have been liberated when the liquids were decomposed on hot iron surfaces or when an electric arc was formed by a short circuit in the transformer. When the liquids are decomposed in a closed room or space where the fumes are confined, it is not safe to breathe the atmosphere there. Although the hydrochloric-acid fumes might be irritating enough to keep men at a safe distance, the Bureau of Mines feels that the advisability of installing such transformers underground is a grave question because it is not always as easy to escape such fumes underground as at the surface. Ventilation in the mine might carry the fumes to men in places where escape would be difficult or impossible.

If these transformers are allowed to be placed underground, the direction of air currents passing them should be such that any toxic gases or vapors that may be given off will be carried into return air courses not regularly traveled by men or forced through traps capable of removing such gases or vapors. Furthermore, every precaution should be taken to provide satisfactory protection which, by opening the circuits, will prevent sustained arcing in the transformers.

FIRE FIGHTING EQUIPMENT AND MATERIALS

Hand-Type Fire Extinguishers

Several important factors must be considered in the application of portable extinguishers to fighting fires in electrical equipment in mines: (1) Some extinguishers are filled with liquids which, when decomposed by electric arcs or heated surfaces, give off poisonous gases; (2) the liquids of some extinguishers are conductors of electricity, therefore their use on electrical fires might result in shock to the fire fighter; and (3) the possible damage to electrical equipment resulting from the corrosive and solvent action of certain chemicals makes it inadvisable to use some extinguishers.

Probably no extinguisher combines all of the desirable qualifications; therefore, it is essential that the limitations of the various types be known.

Carbon Tetrachloride Extinguishers

According to tests by various investigators, extinguishers having carbon tetrachloride as the principal ingredient extinguish electrical fires by virtue of the smothering action of the vapor produced. In some instances the cooling effect of the liquid may prove of value. Although these extinguishers have the desirable quality of not presenting a shock hazard when applied, the objection to them is based on the fact that poisonous gases are given off when the liquid and insulating materials are decomposed in the fire

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The gases,[1] phosgene, hydrogen chloride, and carbon monoxide, are produced in varying quantities depending upon the existing conditions. From this it will be seen that fighting fires with this type of extinguisher without the protection of gas masks or breathing apparatus may prove dangerous, especially in poorly ventilated places or places where ventilating currents may carry the gases over the men. It has been the practice in some mines to equip each locomotive, mining machine, and loading machine with a quart-size extinguisher. While this has the merit of providing quick and ready means of extinguishing incipient fires which otherwise might reach dangerous proportions, the likelihood of the extinguisher being taken from the machine and used in places where the poisonous gases are not diluted and swept away by adequate quantities of air must not be overlooked. Although carbon tetrachloride is a solvent, the amount contained in the hand-type extinguisher is not likely to cause any damage to electrical equipment as the liquid evaporates rapidly.

Soda-Acid Extinguishers

The soda-acid type of extinguisher is not suitable for use on electrical fires because the acid makes the liquid a conductor and a man using one might receive a shock. The corrosive action of the liquid also makes this type of extinguisher unsuitable on account of the damage it might do to the electrical equipment.

Foam-Type Extinguishers

The solutions in extinguishers that discharge foam are conductors of electricity, and although the stream issuing from the extinguisher is normally broken up by many fine bubbles of carbon dioxide it would be unsafe to depend upon this as a protection against shock. Furthermore, since the solutions are conductors of electricity they are likely to cause damage to electrical equipment through short circuits and grounding. In tests[2] by the Bureau of Mines, it was found that the gases produced in fighting a wood fire contained a small quantity (0.15 to 0.31 percent) of carbon monoxide.

Carbon Dioxide Extinguishers

Extinguishers which discharge carbon dioxide gas without water and other liquids offer no shock hazard and will not cause damage to electrical equipment. However, caution must be observed in their application, particularly in places that are not well-ventilated, as the carbon dioxide might displace or dilute the air to the point where the oxygen is insufficient to support life.

1/ Katz, S. H., Gleim, E. J., and Bloomfield, J. J., Carbon Tetrachloride Extinguisher on Electric Fires: Rept. of Investigations 2499, Bureau of Mines, 1923, 16 pp.

2/ Fieldner, A. C., and Katz, S. H., Gases Produced in the Use of Carbon Tetrachloride and Foamite Fire Extinguishers in Mines: Rept. of Investigations 2262, Bureau of Mines, 1921, 6 pp.

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section safety station, and at least four sacks at each pump and mine door along any electrified haulage or door through which an electric wire or cable is passed."

CONCLUSION

Although the material in this paper has been confined largely to the discussion of electrical conditions that might start fires and to descriptions of fires in which electricity was given as the direct cause, the Bureau's files contain many records of explosions of electrical origin that resulted in setting fire to the mines. Summaries[13/] of coal-mine explosions and fires in the United States, compiled annually and published by the Bureau, have shown that in recent years electricity has ranked high among the causes assigned for these disasters. Therefore, any electrical installation that is in a condition to ignite gas or coal dust by sparks and flashes must also be regarded as a potential fire hazard.

The broad experience gained by Bureau engineers in assisting mine officials to control fires and in rescue and recovery operations has resulted in the publication of many recommendations concerning methods of fighting fires and methods of dealing with other vital questions involving safety of life and property. For example, Information Circular 6946 entitled "Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1, 1936," by the Mine Safety Board, issued in June 1937, includes formal decisions regarding mining practices. One of these (Decision 13) relates to "electrical equipment that should be used in coal mines which may become gassy." Bulletin 277, "Safety in Coal Mining," by George S. Rice, issued in 1928, discusses in detail fire-fighting equipment and organization as well as methods that have been found effective in preventing mine explosions.

The study of electrical installations from the standpoint of safety has also resulted in publications giving the Bureau's recommendations on the subject. One of these is Technical Paper 402, issued in 1926 under the title "Safety Rules for Installing and Using Electrical Equipment in Coal Mines."

13/ Harrington, D., and Fene, W. J., Coal-Mine Explosions and Coal- and Metal-Mine Fires in the United States During the Fiscal Year Ended June 30, 1936: Inf. Circ. 6927, Bureau of Mines, 1936, 17 pp.

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